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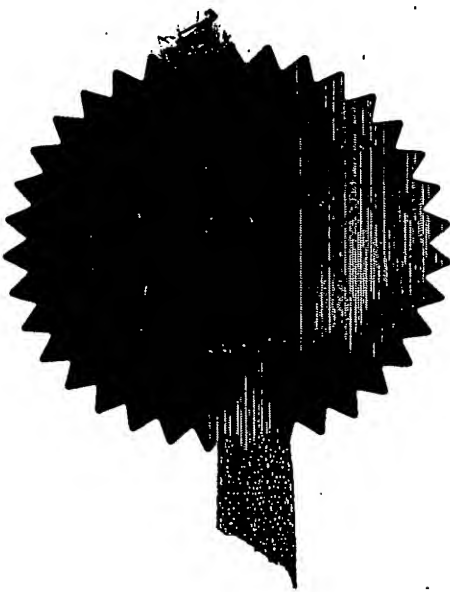
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**Signed**

Stephen Hordley  
27 May 2004

**Dated 27 May 2004**



## Patents Form 1/77

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7APR03 E797932-2 002884  
01/7700 0.00-0307827.6

## Request for grant of a patent

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The Patent Office

Cardiff Road  
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## 1. Your reference

P32391-/CAM/MEA/GMU

## 2. Patent application number

(The Patent Office will fill in this part)

0307827.6

## 3. Full name, address and postcode of the or of each applicant (underline all surnames)

Ocean Power Delivery Limited  
104 Commercial Street  
Edinburgh  
EH6 6NF

Patents ADP number (if you know it)

860401001

If the applicant is a corporate body, give the country/state of its incorporation

United Kingdom

## 4. Title of the invention

Wave Power Apparatus

## 5. Name of your agent (if you have one)

Murgitroyd &amp; Company

"Address for service" in the United Kingdom to which all correspondence should be sent (including the postcode)

Scotland House  
165-169 Scotland Street  
Glasgow  
G5 8PL

Patents ADP number (if you know it)

1198015 ✓

## 6. If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these earlier applications and (if you know it) the or each application number

Country

Priority application number  
(if you know it)Date of filing  
(day / month / year)

## 7. If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application

Number of earlier application

Date of filing  
(day / month / year)

## 8. Is a statement of inventorship and of right to grant of a patent required in support of this request? (Answer 'Yes' if:

Yes

- a) any applicant named in part 3 is not an inventor, or  
b) there is an inventor who is not named as an applicant, or  
c) any named applicant is a corporate body.  
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0065449 04-Apr-03-03-20

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Claim(s)	-	
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Priority documents	-
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Statement of inventorship and right to grant of a patent (Patents Form 7/77)	-
Request for preliminary examination and search (Patents Form 9/77)	-
Request for substantive examination (Patents Form 10/77)	-
Any other documents (please specify)	-

11.

I/We request the grant of a patent on the basis of this application.

Signature	<i>Murgitroyd</i>	Date
Murgitroyd & Company		4 April 2003

12. Name and daytime telephone number of person to contact in the United Kingdom

Mark Earnshaw

0141 307 8400

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**Patents Form 1/77**

0065449 04-Apr-03 03:20

1     Wave Power Apparatus

2

3     This invention relates to a linkage unit, apparatus  
4     and method, for extracting power from water waves,  
5     particularly ocean waves.

6

7     Ocean waves represent a significant energy resource.

8     It is known to use a wave energy converter to

9     extract power from such waves. An improved

10    apparatus is shown in our WO 00/17519A. This shows

11    apparatus for extracting power from ocean waves

12    comprising a number of buoyant cylinder body members

13    connected together at their ends to form an

14    articulated chain-like structure. Each pair of

15    adjacent cylindrical members is directly connected

16    together by coupling members which permit relative

17    rotation of the cylindrical members about at least

18    one axis. Preferably, adjacent coupling members

19    permit relative rotation about mutually orthogonal

20    transverse axes.

21

1 It is an object of the present invention to provide  
2 further improved apparatus and method for extracting  
3 power from waves.

4  
5 According to one aspect of the present invention,  
6 there is provided a linkage unit for use between two  
7 buoyant body members of an articulated apparatus for  
8 extracting power from waves, said linkage unit  
9 interspacing the body members, and comprising  
10 linkage means to conjoin the unit with ends of the  
11 body members to permit relative movement of said  
12 body members about at least two axes.

13  
14 Preferably, the linkage unit also includes one or  
15 more power extraction elements adapted to extract  
16 power from the relative rotational movement of said  
17 body members. More preferably, the power extraction  
18 elements are adapted to resist the relative  
19 rotational movement of said body members, and  
20 thereby provide the power. The power extraction  
21 elements could be integral with, linked to or  
22 separate from the linkage means.

23  
24 The linkage unit preferably permits the movement of  
25 said body members about two axes. The movement axes  
26 could be at any angle thereinbetween, but are  
27 preferably wholly or substantially orthogonal.

28  
29 In one embodiment of the present, separate linkage  
30 means are provided for the movement about each axis.  
31 Each linkage means may be independent, or may be  
32 linked to other linkage means.

1 The linkage unit of the present invention preferably  
2 includes one or more power generation means such as  
3 a generator or other means adapted to store the  
4 power absorbed for future use. The linkage unit may  
5 have separate power generation means for each power  
6 extraction element, which separate power generation  
7 means may be separate or linked. Where linked, one  
8 power generation means may be the primary or  
9 dominant means over other power generation means.

10

11 The nature of the buoyant body members may  
12 correspond with the description of said members in  
13 WO 00/17519, which is included herein by way of  
14 reference. That is, said body members are  
15 preferably substantially elongate, cylindrical, and  
16 will form a chain-like structure. The structure  
17 preferably has a length of the same order of  
18 magnitude as the longest wave length of the waves  
19 from which power is extracted, and may be free to  
20 adopt an equilibrium position with respect to any  
21 instantaneous wave pattern.

22

23 The linkage unit preferably includes one or more  
24 controllers, more preferably one controller or  
25 control means within the linkage unit. The linkage  
26 unit preferably includes sufficient access means,  
27 such as one or more hatches, to allow inspection,  
28 repair and maintenance on site, i.e. as located  
29 between two body members at sea.

30

31 According to a second aspect of the present  
32 invention, there is provided apparatus for

1 extracting power from waves comprising a plurality  
2 of buoyant body members as herein described  
3 interspaced and conjoined by one or more linkage  
4 units as herein described.

5  
6 The apparatus may be further defined and used as  
7 described in WO 00/17519. This includes possibly  
8 including a slack mooring system, and possibly  
9 having means to orientate the apparatus such that  
10 under normal operating conditions, it spans at least  
11 two wave crests. The mooring system may also  
12 include means to vary the angle of orientation of  
13 the chaining of body members to the mean wave  
14 direction to maximise power extraction. The  
15 apparatus may also further comprise means to apply a  
16 roll angle to an axis of relative rotation away from  
17 the horizontal and/or vertical.

18  
19 The apparatus may also include one or more elements  
20 adapted to resist relative rotational movement of  
21 said body members, which may be a spring and/or  
22 damping elements. Magnitudes of constraint could be  
23 applied to a plurality of said elements in order to  
24 induce a cross-coupled response.

25  
26 The apparatus could also be provided with a  
27 ballasting system, which possibly comprises ballast  
28 tanks comprising inlet means and outlet means, and  
29 wherein the ballasting system varies the roll bias  
30 angle of the chain-like structure.

1 According to a third aspect of the present  
2 invention, there is provided a method of extracting  
3 power from waves comprising the steps of:  
4       deploying an apparatus as hereinbefore defined  
5       comprising a plurality of buoyant body members,  
6       each adjacent pair of body members being  
7       interspaced by and conjoined by a linkage unit  
8       as hereinbefore defined in such a way as to  
9       permit relative rotational movement of said  
10      body members under action of the waves, each  
11      linkage unit including elements adapted to  
12      resist and extract power from the relative  
13      rotational movement of said bodies in at least  
14      two axes;  
15  
16      orientating the structure such that the front  
17      end of the structure faces into the oncoming  
18      waves;  
19  
20      extracting the power absorbed in the or each  
21      linkage unit.  
22  
23 Preferably, the apparatus of the method includes  
24 independent systems for each axis of relative  
25 movement, and means to operate each system either  
26 independently or in a linked action. One advantage  
27 of this is that the failure of one system still  
28 allows the other system to operate independently,  
29 maintaining restraint on the linkage. Alternatively  
30 or additionally, where there are a plurality of  
31 individual linkage means or power extraction means  
32 acting about each axis of rotation, the apparatus



1 may include further independent systems that are  
2 split or otherwise designed in such a way that in  
3 the event of failure on one of the systems,  
4 restraint may be maintained about both or all axes  
5 of relative movement.

6  
7 According to fourth aspect of the present invention,  
8 there is provided a method of manufacture of  
9 apparatus for extracting power from waves as herein  
10 before defined, which method comprises the step of  
11 interspacing and conjoining each set of adjacent  
12 body members with a linkage unit. Preferably, the  
13 method can be carried out close to site, on site or  
14 in situ, because the linkage unit(s) can be fully  
15 assembled, analysed and tested, for example on a  
16 test rig, relating to its power extraction prior to  
17 its installation and use.

18  
19 Embodiments of the present invention will now be  
20 described by way of example only with reference to  
21 the accompanying drawings in which:

22  
23 Figures 1a and 1b show overall plan and side views  
24 of apparatus of the present invention;

25  
26 Figure 2 shows a perspective view of part of prior  
27 art apparatus according to the one embodiment of the  
28 invention shown in WO 00/17519 for directly linking  
29 body members;

30  
31 Figure 3 shows front and inside detail of one part  
32 of Figure 2;

1 Figure 4 shows a schematic line drawing of the  
2 conjunction in Figures 2 and 3;

3

4 Figure 5 shows a detail of the apparatus in Figure 1  
5 illustrating a linkage unit of the present  
6 invention;

7

8 Figures 6, 7 and 12 show different external and  
9 part-internal views of the linkage unit in Figure 5;

10

11 Figure 8a shows detail of the linkage between the  
12 linkage unit and a buoyant body member;

13

14 Figure 8b shows detail in circle A in Figure 8a;

15

16 Figure 8c shows detail of the dual seal system in  
17 circle B in Figure 8a;

18

19 Figure 9 shows a front perspective internal detail  
20 of a linkage unit of Figure 5;

21

22 Figure 10 shows a front plan internal line drawing  
23 of linkage unit of Figure 9; and

24

25 Figures 11a and 11b show two schematic hydraulic  
26 systems for the linkage unit.

27

28 Referring to the drawing, Figures 1a and 1b show an  
29 apparatus 2 for extracting power from waves having,  
30 for this example, four buoyant body members 4, 6, 8,  
31 10. The number, size and shape of the body members  
32 involved is generally determined by the annual wave

1 climate of the locality in which it is used, and by  
2 the conditions it is likely to encounter.

3

4 The body members 4, 6, 8, 10 may be of any size or  
5 shape. Generally they are cylindrical, and have  
6 sufficiently small depth and freeboard to experience  
7 complete submergence and emergence in large waves  
8 (as is discussed in our WO 00/17519). That is, the  
9 overall chain-like structure of the apparatus 2 may  
10 be configured to encourage hydrostatic clipping in  
11 extreme conditions. The body members 4, 6, 8 and 10  
12 may be provided with fins, bilge keels or other  
13 protrusions to add hydrodynamic damping to any  
14 direction of motion desired.

15

16 The front body member 4 is provided with a  
17 streamlined (for example conical) front end to  
18 minimise drag in extreme seas, whilst the rear body  
19 member 10 has a flat rear end to increase damping  
20 along the axis of the chain structure to add damping  
21 to the mooring response.

22

23 The body members 4, 6, 8, 10 may be formed from any  
24 suitable material. Concrete is one suitable  
25 material, although steel or fibreglass are also  
26 useable.

27

28 The body members 4, 6, 8, 10 are preferably  
29 ballasted to float with its centre line on or near  
30 the water-plane (approximately 50% displacement by  
31 volume). The body members 4, 6, 8, 10 could include  
32 an active or passive ballasting system, which varies

9

1 the level at which the individual body members or  
2 the complete apparatus floats. If incorporated, the  
3 ballasted system may be capable of being disabled  
4 and/or removed. The ballasting system hastens the  
5 onset of hydrostatic clipping in extreme seas, thus  
6 helping to minimise the maximum loads and bending  
7 moments which the apparatus 2 is subject to in  
8 adverse weather conditions. A variable ballasting  
9 system useable with the present invention is shown  
10 and discussed in our WO 00/17519.

11  
12 Figures 2-4 show one arrangement for connecting two  
13 similar body members of the apparatus for extracting  
14 power shown in WO 00/17519. Between the body  
15 members 12 of the prior art apparatus 11, there is  
16 shown a joint spider 14 adapted to provide  
17 rotational movement directly between the body  
18 members 12 about two orthogonal axes. Seals 16  
19 cover stubs 17, show more clearly in Figure 4, which  
20 actuate rams 18 in sealed compartments 20 at the end  
21 of each body member 12.

22  
23 Whilst the arrangement shown in Figures 2-4 provides  
24 the benefit of a wave energy converter, it requires  
25 the manufacture and use of the linkage mechanisms  
26 and ram-housing compartments to be made and attached  
27 separately to the remaining parts of the body  
28 members 12. A typical length of a body member is 27  
29 meters long, requiring either significant  
30 transportation of completed body members made in a  
31 suitable location, or significant assembly of the  
32 separate compartments 20 to the main lengths of body

10

1 members 12 on site, generally at or near beaches and  
2 other sea locations, which may not provide suitable  
3 assembly conditions.

4  
5 Furthermore, each ram-housing compartment 20  
6 requires its own hydraulic and generation  
7 components, and must be separately tested prior to  
8 installation and use. Such testing may or may not  
9 be in conjunction with the main part of the body  
10 members 12, being 27 meters long. Also, in the  
11 event of failure of the linkage or joint hydraulic  
12 system, restraint on the joint may be lost, possibly  
13 leading to further damage or failure. Whilst it is  
14 possible to provide independent systems in this  
15 arrangement for each of the individual restraint  
16 means acting about a particular axis of rotation, it  
17 is not economic to do so.

18  
19 As shown in Figures 1, 5, 6 et al, the present  
20 invention provides a linkage unit 30 for use between  
21 two buoyant body members 4, 6, 8, 10, and comprises  
22 linkage means to conjoin the unit 30 with the ends  
23 of the body members 4, 6, 8, 10 to permit relative  
24 movement of said body members 4, 6, 8, 10 about two  
25 axes. The linkage unit 30 is generally the same  
26 shape as the body members 4, 6, 8, 10, for example  
27 cylindrical, and could be for example approximately  
28 5 meters in length.

29  
30 The linkage means is shown in more detail in Figures  
31 7 and 8a. Each end of the linkage unit 30 has a set  
32 of two bearings 32, each set of bearings 32 set at

11

1 substantially orthogonal angle to the other set.  
2 Each set of bearings 32 is adapted to hold a pin 34  
3 (not shown in Figure 7) along their axis.  
4  
5 Also attachable to each pin 34 are bearings 36 on  
6 the relevant ends of the body members 4, 6, 8 and  
7 10. The body member bearings 36 are preferably  
8 conjoined with the main segments of the body  
9 members, 4, 6, 8, 10 by means of end-member caps 38,  
10 made for example of steel. Thus, an end cap 38 need  
11 only comprise a cast or otherwise manufactured piece  
12 having two bearings and two ram housings. No moving  
13 parts are involved, leading to significantly reduced  
14 manufacture, attachment, maintenance and repair,  
15 etc. Moreover, there are no complex or active  
16 components within the main body member segments.  
17 The linkage bearings may be provided with external  
18 seals to allow the bearings and pins to be accessed  
19 for inspection, maintenance or repair insitu or  
20 near-site without water ingress.  
21  
22 Thus, each linkage unit 30 allows rotational  
23 movement about one axis with one body member 4, 6,  
24 8, 10, and rotational movement about an orthogonal  
25 axis with its other conjoined body member 4, 6, 8,  
26 10. In this way, the linkage unit 30 allows the  
27 body members 4, 6, 8, 10 relative movement about two  
28 axes (based along the axes of the pins 34).  
29  
30 The relative movements between the linkage units 30  
31 and body members 4, 6, 8 and 10 are resisted by  
32 power extraction elements, which extract power from

~~12~~ 12

1 this relative motion. The power extraction elements  
2 may be any suitable means adapted to be activated by  
3 this relative motion. One such means is a hydraulic  
4 ram and piston assembly.

5

6 In the present embodiment of the invention shown,  
7 two hydraulic ram assemblies 40 are provided at each  
8 end of the linkage unit 30, and on each side of the  
9 linkage unit-body member linkage means. The parts  
10 of the assemblies 40 between the unit 30 and end  
11 caps 38 will generally be enclosed by flexible seals  
12 41, known in the art. Inner diaphragm seals 43  
13 could also be incorporated to assist single seal-  
14 failure problems, as shown and described in Figure  
15 8c.

16

17 As shown in Figure 8b, the end of the ram of a ram  
18 and piston assembly 40 can travel along a suitable  
19 ram cavity 42 within the end cap 38 of a body member  
20 4, 6, 8, 10. The role of the cavity 42 is two-fold:

21

22 1. To provide a sealed compartment to prevent  
23 water ingress into the end caps 38 in the event  
24 of failure of the external flexible seal 41,  
25 and,

26 2. In the event of failure of the hydraulic  
27 systems, to allow the ram 40 to break free at  
28 the attachment pin 45 if it reaches its end  
29 stop (in a manner similar to a shear pin on  
30 outboard motor propellers). This limits the  
31 maximum loads that the structure must be  
32 designed to sustain, reducing cost and the

1           likelihood of major or complete failure. In  
2           the event of the shear pin breaking, the cavity  
3           42 is provided with a weak end wall to allow  
4           the ram 40 to punch through, and therefore give  
5           greatly increased joint motion to prevent  
6           extreme loads in the structure.

7  
8           Figure 8b does not show the inner and outer seals 41  
9           and 43 for clarity.

10  
11           Figures 9 and 10 show internal details of the  
12           linkage unit 30. One set of bearings 32 are shown,  
13           set at a substantially orthogonal angle to two  
14           hydraulic ram assemblies for connecting the shown  
15           face of the linkage unit 30 shown to a body member  
16           4, 6, 8, 10. The first ram assemblies 42 are  
17           described as "Sway rams A and B" in Figure 10.  
18           Figure 10 shows orthogonally located hydraulic ram  
19           assemblies 44, described as "Heave rams A and B" for  
20           attachment of the linkage unit 30 to an oppositely  
21           faced body member 4, 6, 8, 10.

22  
23           Heave ram A and Sway ram A are connected to a first  
24           main manifold 46 which can feed towards a central  
25           manifold 48. Similarly, Heave ram B and Sway ram B  
26           are connected to a second main manifold 50 which can  
27           feed via a one way valve into the central manifold  
28           48. The central manifold 48 controls top and bottom  
29           motors 52, 54.

30  
31           Figures 9 and 10 also show Accumulators 1 and 2 and  
32           reservoirs 1 and 2 which feed into the central



1 manifold 48, as well as Gas backup bottles 1 and 2.  
2 The back-up bottles 1 and 2 provide the optimum gas  
3 to oil volume ratio ensuring optimal energy storage  
4 over the required pressure range.

5  
6 In use, the rams 42, 44 pump high pressure oil into  
7 the accumulators via the manifolds 46, 48 and 50.  
8 The pressure in the accumulators can be matched to  
9 the incident sea state by controlling the rate at  
10 which the oil flows out through the motor.

11  
12 The configuration shown in Figures 9 and 10 has the  
13 advantage of being two sets of hydraulic and  
14 generation components providing split hydraulic  
15 circuits through the two main manifolds 46, 50.  
16 This gives the system redundancy in the event of  
17 failure of a single circuit, allowing the system to  
18 maintain restraint of the joint between the body  
19 members 4, 6, 8, 10. This concept is similar to  
20 that of dual circuit brakes on a car. This is shown  
21 in more detail in Figures 11a and 11b.

22  
23 Figure 11a shows schematically a first useable split  
24 hydraulic circuit system inside the linkage unit 30.  
25 The first circuit system is effectively split by  
26 axis of rotation, such that Sway Rams A and B 42  
27 serve a first circuit by feeding into one High  
28 Pressure Accumulator 1, and Heave Rams A and B 44  
29 serve a second circuit feeding into a second High  
30 Pressure Accumulator 2, all through the outlet  
31 valves 70. The pressured oil operates respective  
32 hydraulic motors 52, 54, which can operate

1     respective electrical generators 60, excess pressure  
2     going through respective heat exchanges 62 to Low  
3     Pressure Reservoirs 1 and 2, before returning to the  
4     Rams 42, 44 through inlet valves 72.

5  
6     The two circuits meet at the common central manifold  
7     48, such that for normal operation, the two circuits  
8     can run linked, thereby increasing efficiency,  
9     especially in small seas. Each half of the  
10    hydraulic circuit can feed the separate hydraulic  
11    motors 52, 54, set to allow generation when the  
12    system is to be linked or to be separated.

13  
14    With the circuits linked in small seas (when the  
15    system is below 50% power), this allows a single  
16    generator to be feed by both hydraulic circuits.  
17    This minimises the working hours of each generator,  
18    and allows the single generator to run at a nearer  
19    full load, dramatically increasing efficiency. In  
20    the event of a fault or leak with one half of the  
21    system, the circuits can be separated to allow the  
22    other half to function independently, maintaining  
23    restraint on the joints. The control of the split  
24    systems can be via the bi-directional linking valves  
25    58 in the central manifold 48.

26  
27    Figure 11b shows schematically a second useable  
28    split hydraulic circuit system, wherein the two  
29    circuits are divided to separately serve the Sway  
30    Rams and Heave Rams on each axis of rotation,  
31    divided such that each system serves one ram from  
32    each axis of rotation, ensuring that restraint is

1 both joint axes in the event of a single hydraulic  
2 circuit system failing. Again, the High Pressure  
3 Accumulators 1 and 2 are linked by bi-directional  
4 link valves 58 to allow separate or linked operation  
5 of the circuits, depending upon sea conditions.

6  
7 The motors 52, 54 are connected to a power  
8 conversion unit or units 60, which may comprise one  
9 or more parts. The power from the unit 60 could be  
10 connected directly to the grid, or used directly or  
11 indirectly to produce a useful by-product. Examples  
12 of useful by-products are hydrogen through  
13 electrolysis, and desalinated water.

14  
15 The linkage unit 30 also includes one or more heat  
16 exchangers 62, such as an oil/water water heat  
17 exchanger, to release excess absorbed power back  
18 into the sea. This allows the linkage unit 30 to  
19 continue generating at full capacity in extreme  
20 conditions. In the event of electrical grid  
21 failure, this also provides the necessary thermal  
22 load.

23  
24 The hydraulic oil used by the apparatus is  
25 preferably specified to be biodegradable, and non-  
26 toxic to water organisms.

27  
28 The linkage unit 30 includes one or more access  
29 portals such as hatches. In the embodiment shown in  
30 the accompanying drawings, the linkage unit 30 has a  
31 first man-assessable hatchway 64 and a larger main-  
32 assessable hatchway 66. The linkage unit 30 may

1 also include a separate or equipment loading  
2 hatchway.

3  
4 Figure 12 shows a further schematic part cross-  
5 sectional perspective of the linkage unit 30  
6 attached to a buoyant body member 6. Parts of the  
7 linkage unit 30 have not been shown in order to  
8 better illustrate the position of parts of the power  
9 conversion units already installed 72, and a further  
10 part 74 being installed through the main-access  
11 hatchway 66.

12  
13 By housing all the significant components and parts  
14 for the power extracting in one linkage unit, this  
15 allows the unit to share components such as  
16 manifolds, pipework, fittings, mountings, power  
17 supply and batteries, etc. within a single unit,  
18 compared with previous known wave energy converters,  
19 including that shown in WO 00/17519. The unit 30 is  
20 therefore adapted for maintenance or repair within  
21 one unit, rather than requiring separate  
22 inspections.

23  
24 Furthermore, the collations of the components in a  
25 single unit also allows their control to be carried  
26 out by a single joint controller, leading to further  
27 cost savings.

28  
29 The configuration of the linkage unit 30 shown in  
30 the attached drawings also allows the hydraulic oil  
31 heat-exchangers 62 to be housed in the "U" channels  
32 at the ends of the linkage unit 30. The use of a

1 'box-cooler' unit in this space means that it is  
2 well protected, whilst generating sufficient flow of  
3 water past it to keep the cooler compact.

4

5 A further improvement in the present invention is  
6 the siting of the main bearings (and ram end  
7 bearings) so as to allow access from inside the unit  
8 30 (or the body member end caps 38) for inspection  
9 and replacement. Preferably the unit 30 has  
10 external seals around each component extending from  
11 the unit 30, to prevent flooding, and to protect the  
12 hydraulic rams and other components from corrosion.  
13 This further assists when the inspection and/or  
14 replacement of components is taken place, such that  
15 the unit 30 does not have to be dry-docked for  
16 maintenance or repair of a ram, seal or other  
17 components. More preferably, each ram exit has two  
18 flexible seals, e.g. as "inner" and "outer", to  
19 provide back-up in the event of a failure.

20

21 A further advantage concerns the avoidance of the  
22 use of a joint spider 14 as shown in Figures 2-4.  
23 In this arrangement, the rams form the main load  
24 path through the whole apparatus. This is because  
25 the loads pass from one body member, through the  
26 main bearing into the rear of the hydraulic ram, and  
27 then pass straight through the module into the rod  
28 end mount in the end of the next body member. In  
29 the present invention, loads through the linkage  
30 unit 30 are reduced to shear loads, other  
31 environmental loads, and any small imbalance loads  
32 due to the differential areas of the rams. This

1 means that the configuration can be more  
2 structurally efficient. Moreover, as loads on the  
3 linkage unit structure are small, access portal size  
4 can be significant larger making installation of the  
5 components much easier. Lower structural loads  
6 around access portals also allows simpler sealing  
7 systems to be used.

8  
9 The apparatus 2 is referenced predominantly against  
10 itself rather than against the shore or the seabed.  
11 This self referencing is achieved by the apparatus 2  
12 being of length comparable to the incident  
13 wavelength, and the apparatus 2 being orientated  
14 relative to incident waves in a direction such that  
15 the apparatus 2 spans at least two crests of the  
16 incident waves.

17  
18 The configuration and orientation of individual  
19 joints, and the type and rating of individual power  
20 extraction elements which comprise a particular  
21 apparatus, are selected to maximise the power  
22 extracted from a given sea state, but to ensure  
23 survival in extreme conditions. In particular an  
24 overall roll bias angle ( $\psi$ ) is preferably applied to  
25 the joint axes away from the horizontal and vertical  
26 so as to generate a cross coupling of the heave and  
27 sway motions of the converter in response to wave  
28 forces. This response may be resonant with the  
29 incoming waves to further increase power capture.

30  
31 Additionally or alternatively, the apparatus could  
32 include an active system to control the roll bias

1 angle ( $\psi$ ). In this way the active control system  
2 also controls the response of the apparatus in  
3 waves.

4  
5 The same selection criteria determine the preferred  
6 orientation in relation to incident waves of the  
7 complete apparatus, when deployed.

8  
9 Maximum power absorption by, and thus maximum power  
10 output from, the apparatus is generally achieved by  
11 coupling its body members using joints orientated in  
12 different directions, by applying the roll bias  
13 angle ( $\psi$ ) to the joints, by applying different  
14 constraints to each direction to induce a cross-  
15 coupled response of varying magnitude and form which  
16 may be tuned to suit the wave conditions, and by  
17 using a system of moorings to present the apparatus  
18 in a preferred orientation relative to incoming  
19 waves.

20  
21 The mooring system may also provide significant  
22 physical restraint or excitation to the apparatus so  
23 as to modify the overall response.

24  
25 In calm weather, where wavelengths are relatively  
26 short, and wave amplitudes are small, there is a  
27 requirement to maximise power absorption by the  
28 apparatus.

29  
30 In extreme weather, where wavelengths are longer and  
31 wave amplitudes are larger, survival of the

21

1 apparatus is of greater importance than power  
2 absorption efficiency.

3  
4 The total length of the assembled structure is  
5 therefore selected to be sufficiently long to  
6 provide adequate self referencing of the structure  
7 in short wavelengths where not much power is  
8 available and there is a requirement to maximise  
9 power absorption, and sufficiently short to 'hide'  
10 in long wavelengths associated with storm waves in  
11 order to survive. If the wavelength is much greater  
12 than the length of the structure, then the structure  
13 cannot extend from peak to peak, and the maximum  
14 movement of any part of the structure relative to  
15 any other part is less than the amplitude of the  
16 wave, so that the structure 'hides' in the long  
17 wavelength. In other words, the structure loses the  
18 ability to reference itself against the wavelength.  
19 This effect is further discussed in WO 00/17519.

20  
21 Each end face of the intermediate body members 6, 8  
22 and the linkage unit 30, and the inner end faces of  
23 the end body members 4, 10, could be chamfered to  
24 allow clearance for extreme joint motion. The  
25 chamfered portions may lie on planes intersecting  
26 the joint axes in order that opposing faces meet to  
27 form a cushioning squeeze film. In the event that  
28 end-stops of the ram assemblies are reached this has  
29 the effect of reducing impact load.

30  
31 The body members could also incorporate areas of  
32 sacrificial structure which allow very large joint



1 angles before the overall structural integrity or  
2 flotation of the apparatus is compromised. These  
3 areas of sacrificial structure behave in a manner  
4 similar to crumple zone on a car.

5

6 Other components of the apparatus and the ram  
7 assemblies could similarly be designed to fail in a  
8 benign manner which does not compromise the  
9 integrity of the complete system when necessary.

10

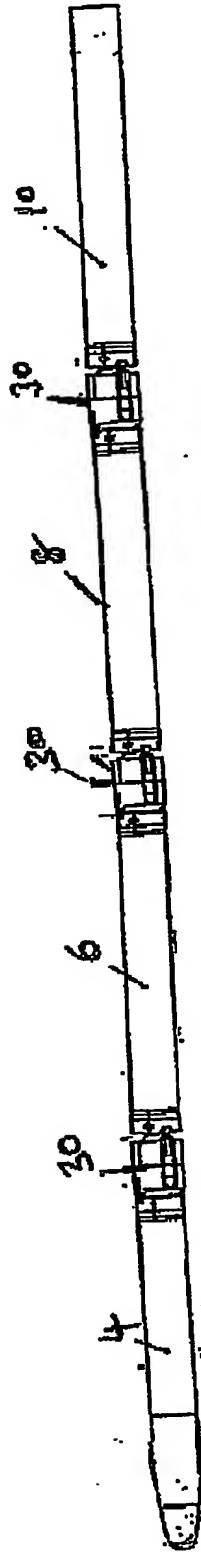
11 In small seas, power capture can be maximised by  
12 orientating the apparatus 2 at an angle to the  
13 incident waves. In extreme seas, it is preferable  
14 that the apparatus 2 be orientated end on to the  
15 incident waves. This may be achieved by using an  
16 active or passive mooring system to present the  
17 apparatus 2 at an angle to the waves appropriate for  
18 maximum power capture, or appropriate for survival,  
19 as required. Illustrations of some possible mooring  
20 configurations are shown in WO 00/17519.

21

22 The present invention provides a single, compact,  
23 self-contained and manufacturable unit. This lends  
24 itself to efficient, centralised manufacture and  
25 testing, for shipment to a final assembly site.  
26 Thus, the main body members could be manufactured near  
27 the deployment site, and would require minimal fit-  
28 out before final assembly with the linkage unit.  
29 Further, the linkage units can be fully tested prior  
30 to transportation and installation on-site.  
31 Moreover, all the high technology, high value and  
32 data components are within a single unit.

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Fig 1a



2

Fig 1b

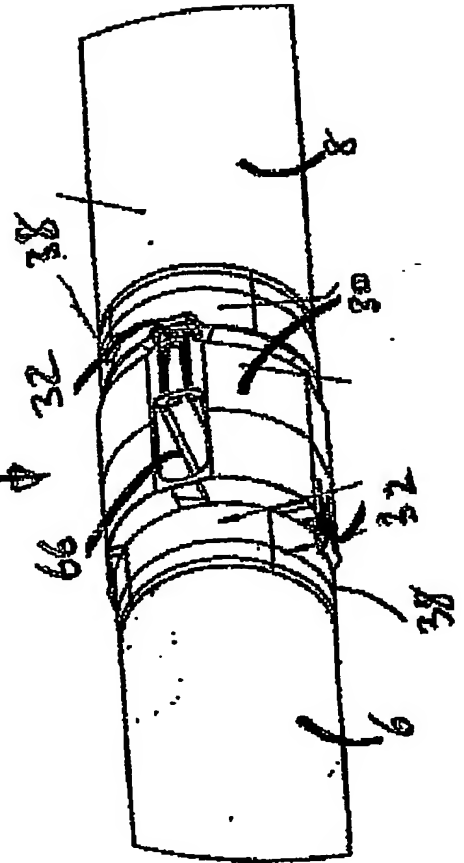
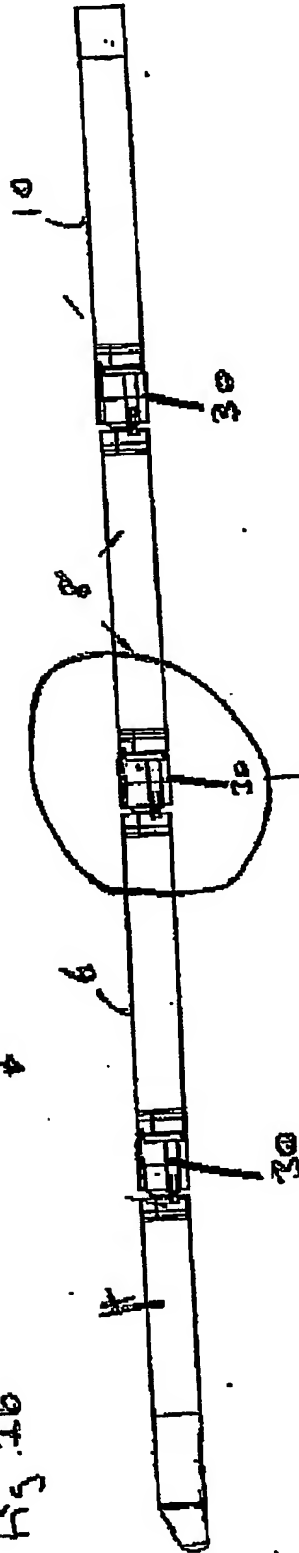
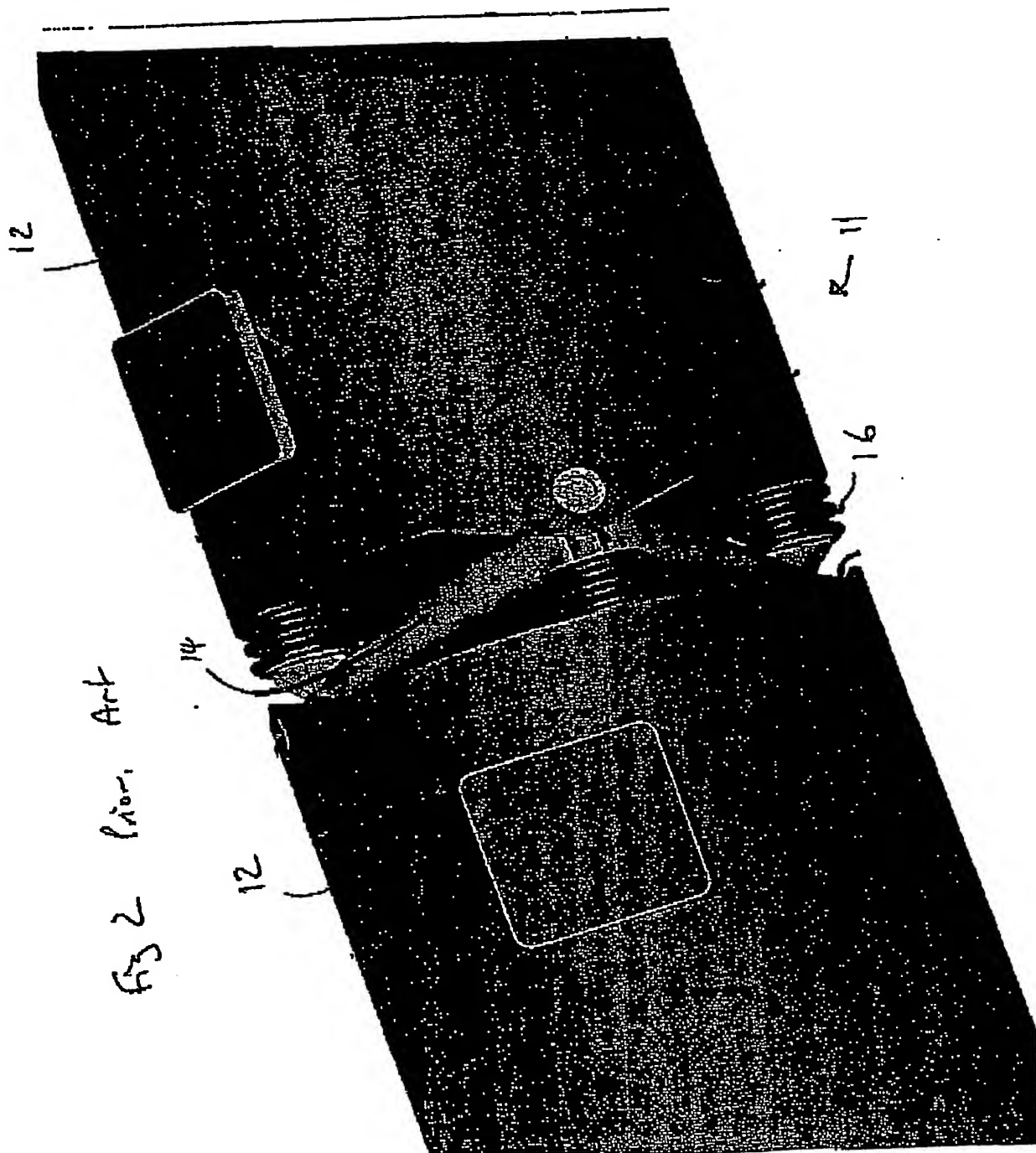


Fig 5

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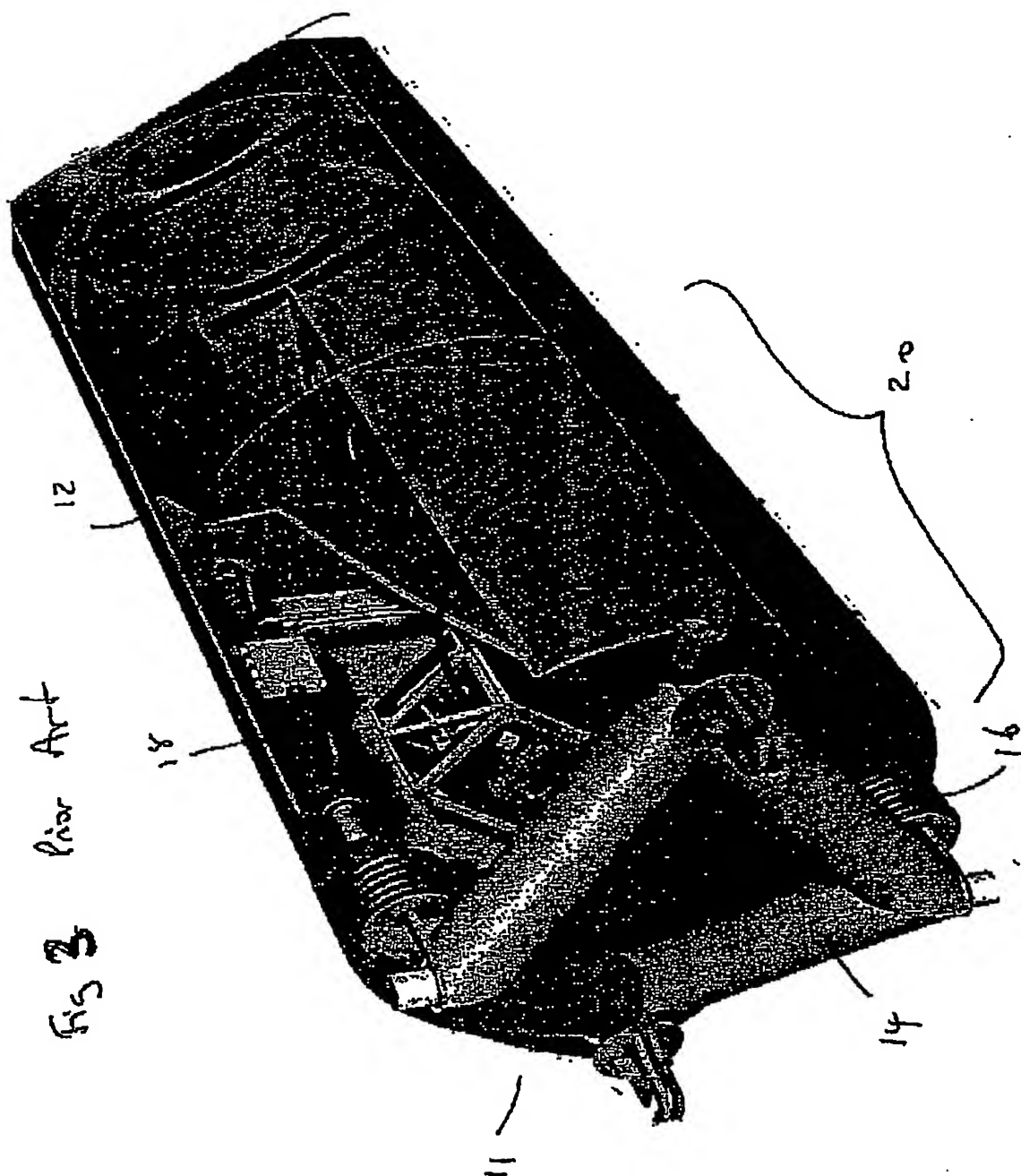


Fig 3 Prior Art

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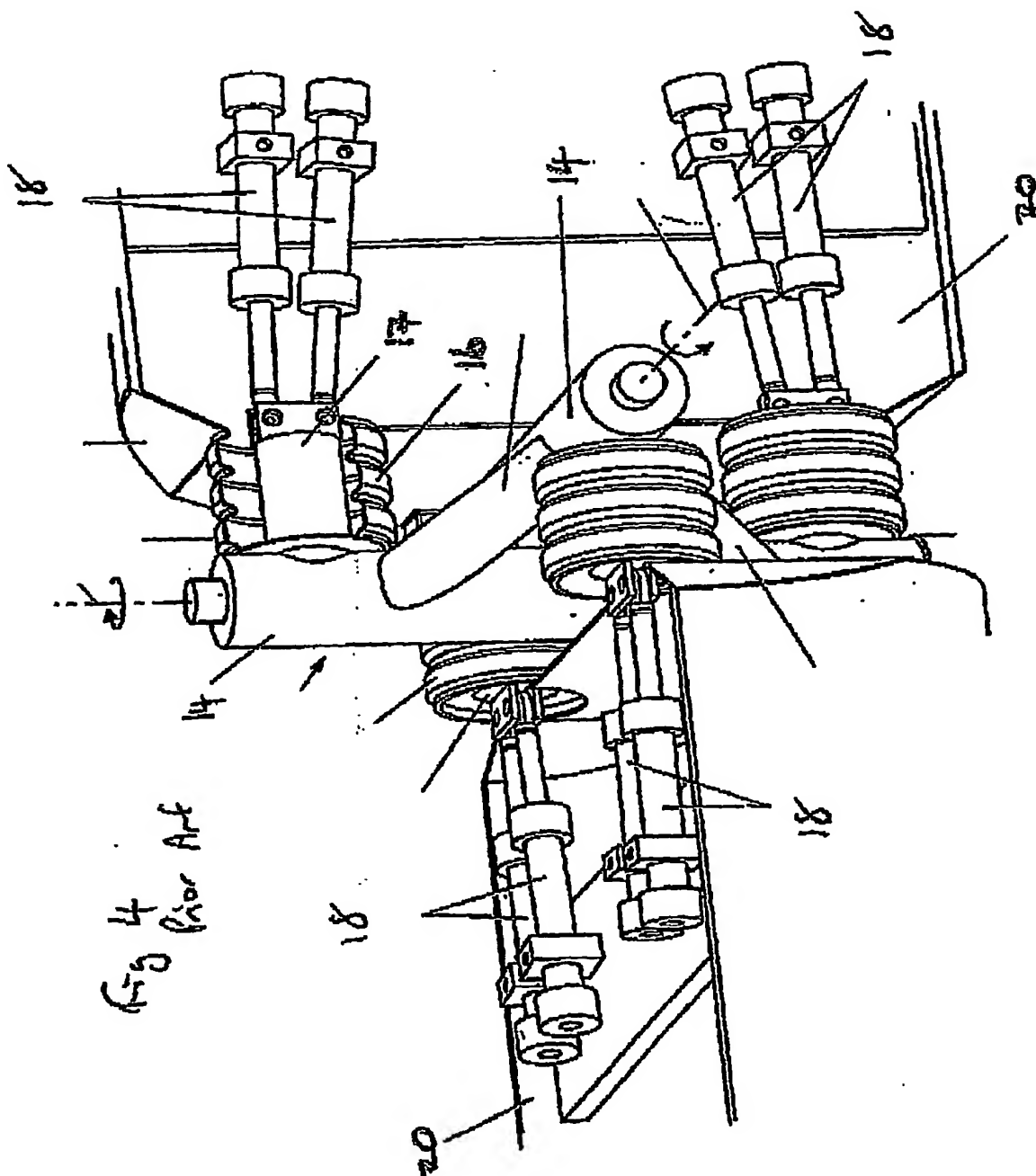
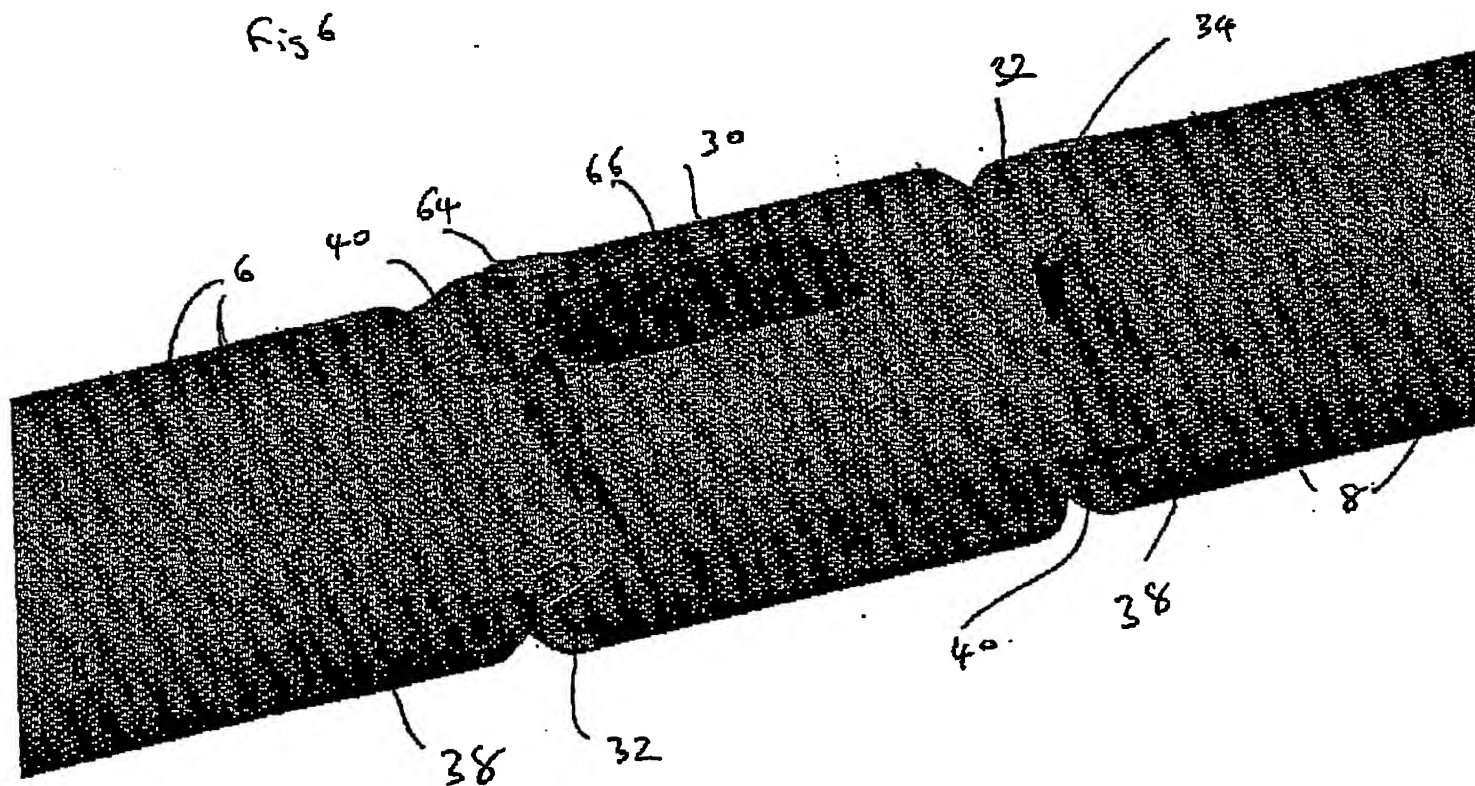


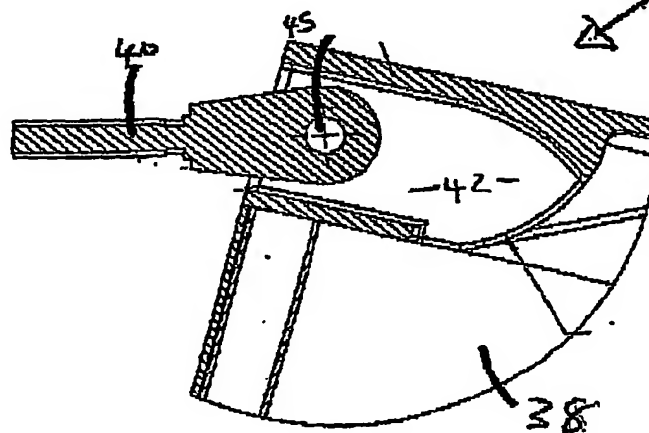
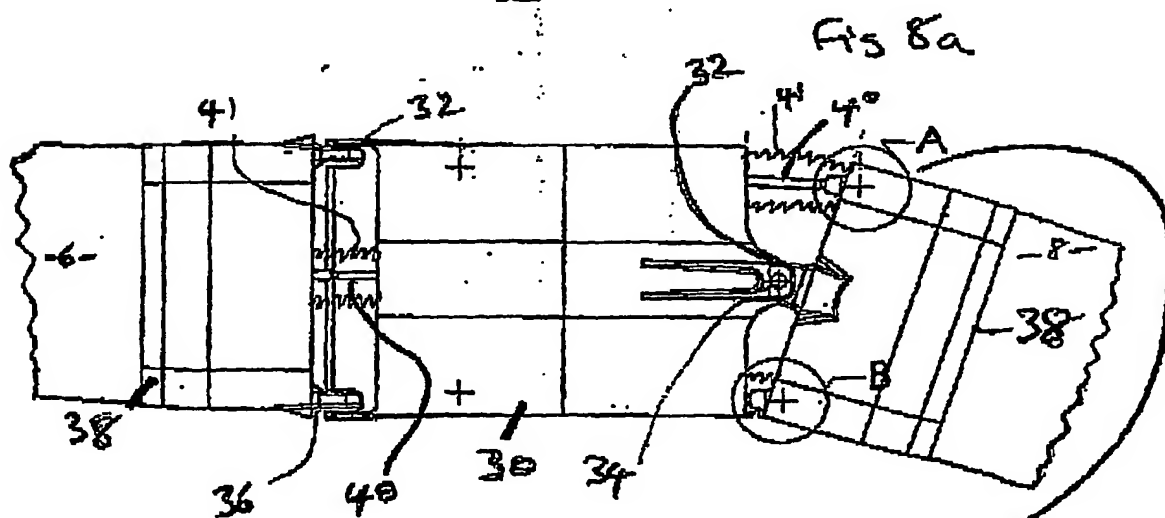
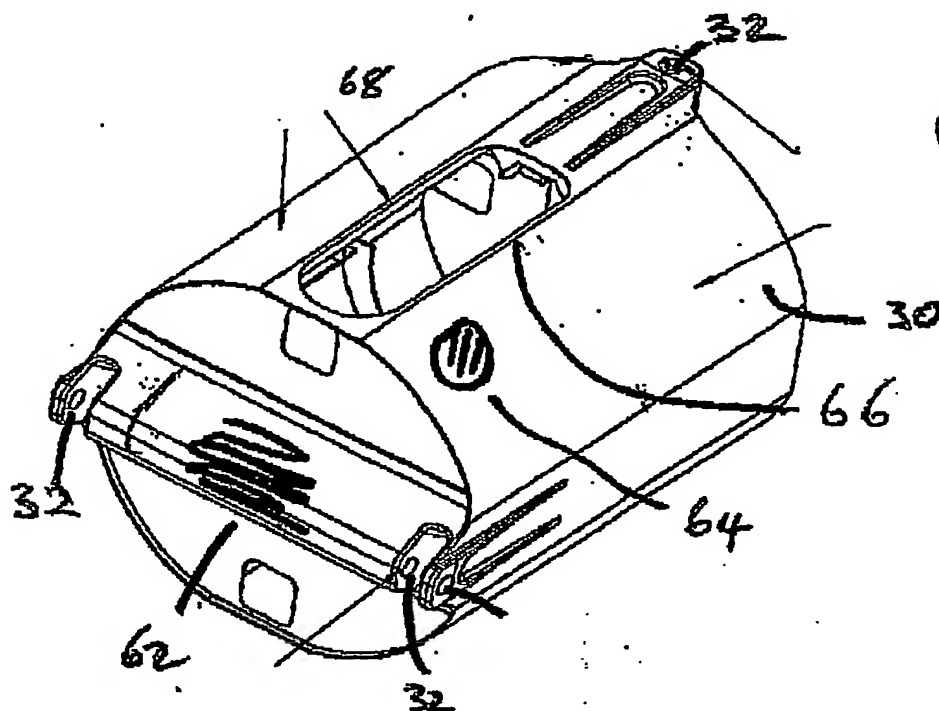
Fig 4 Prior Art

S/R

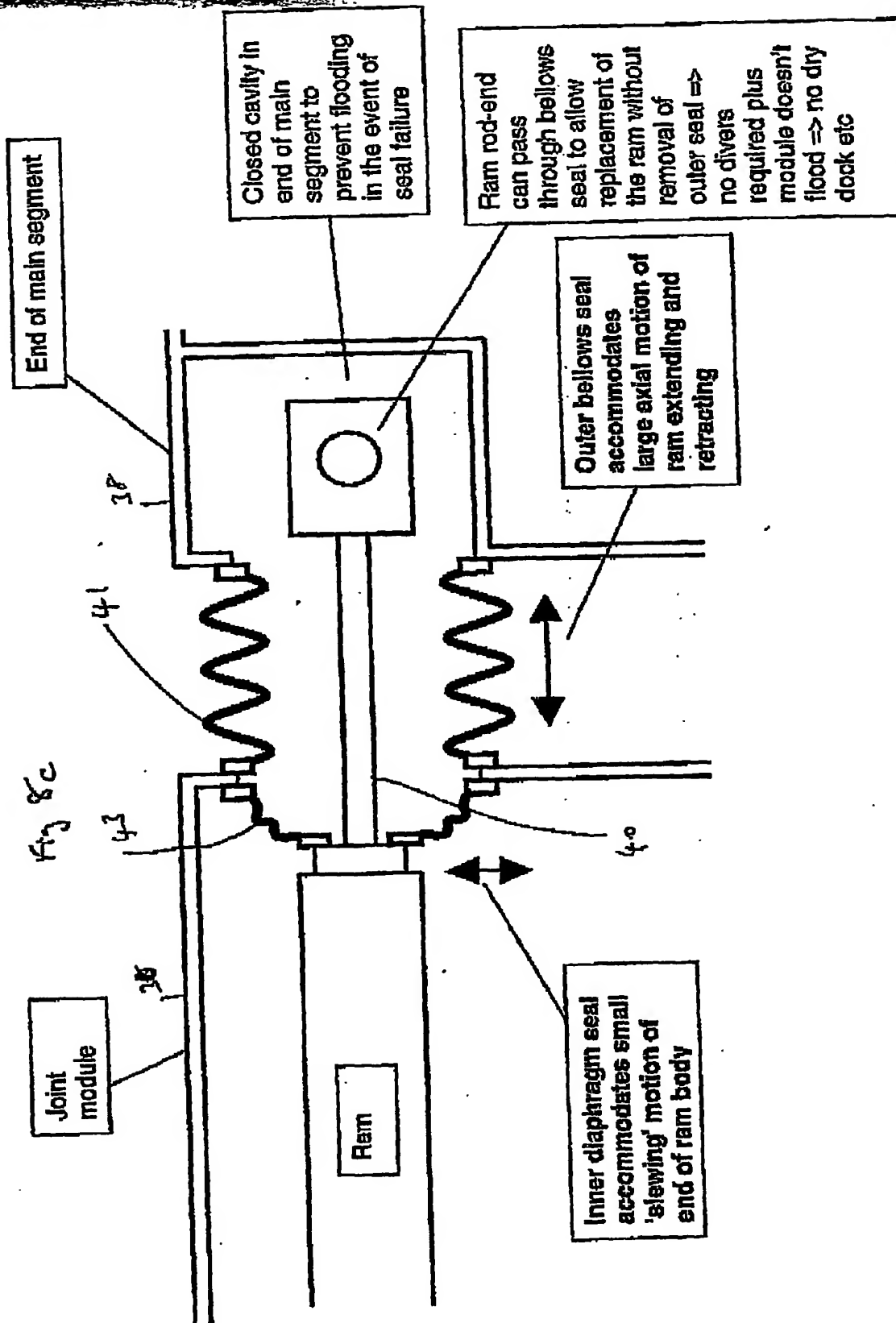
Fig 6



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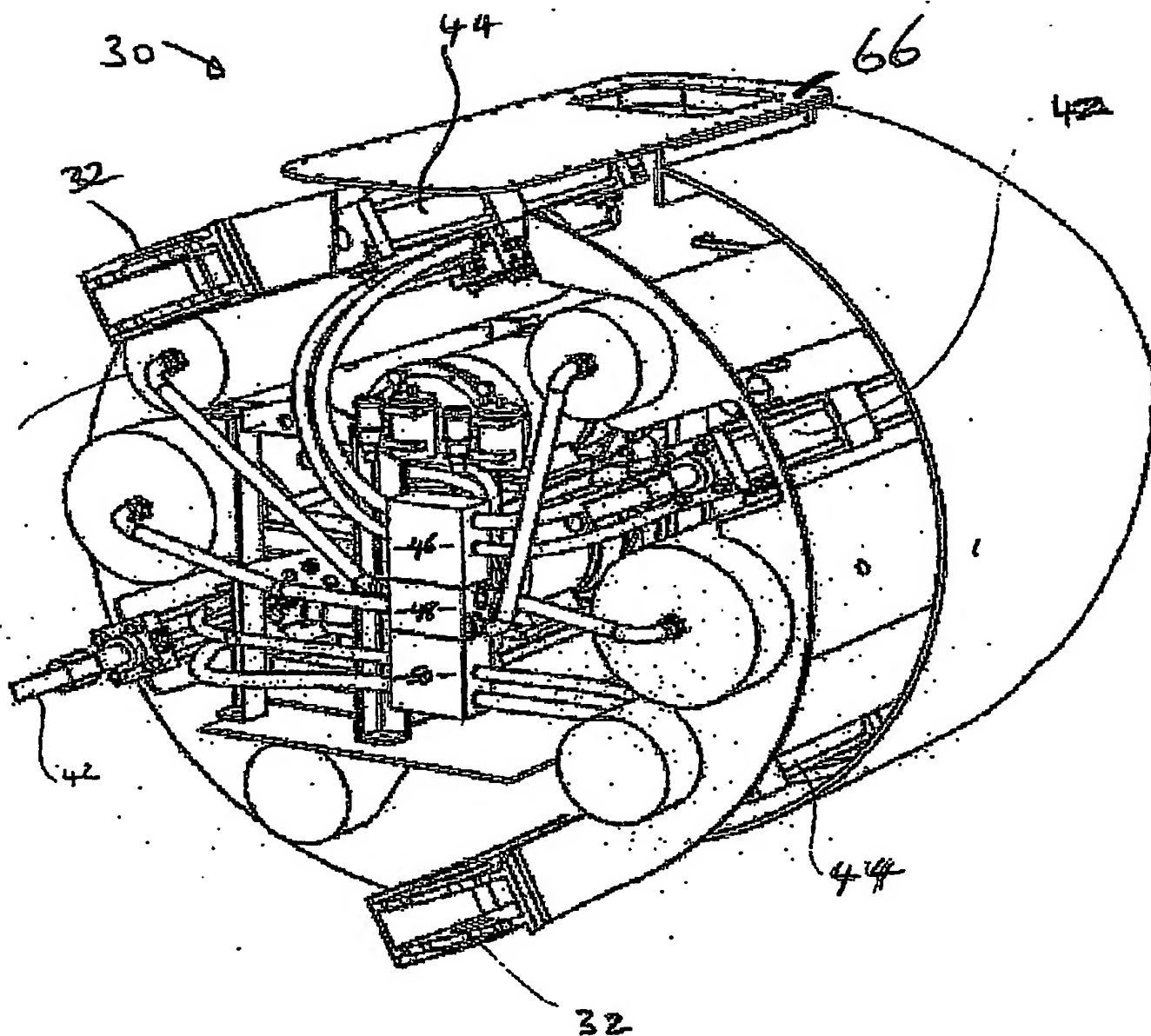
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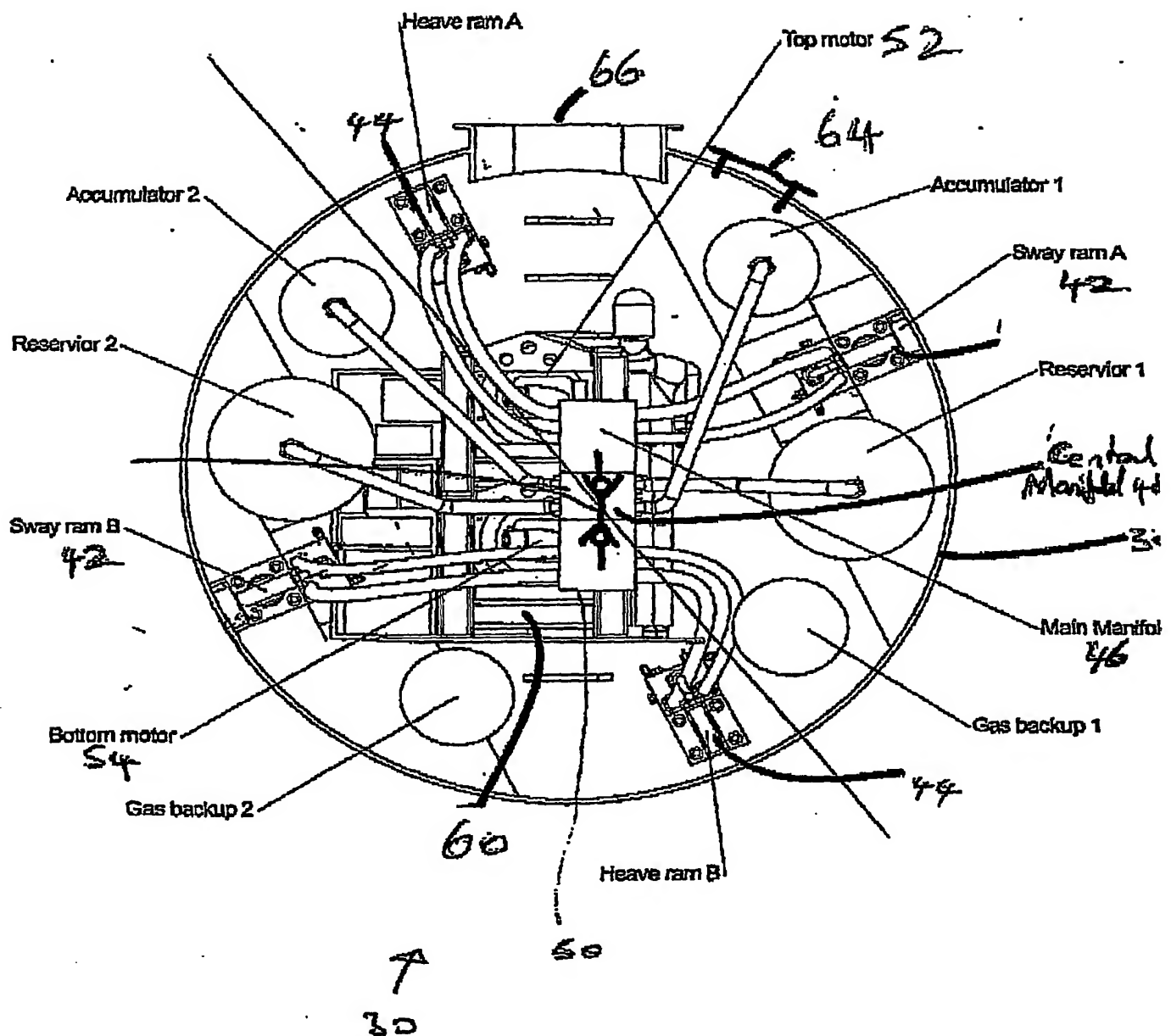
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Fig 9

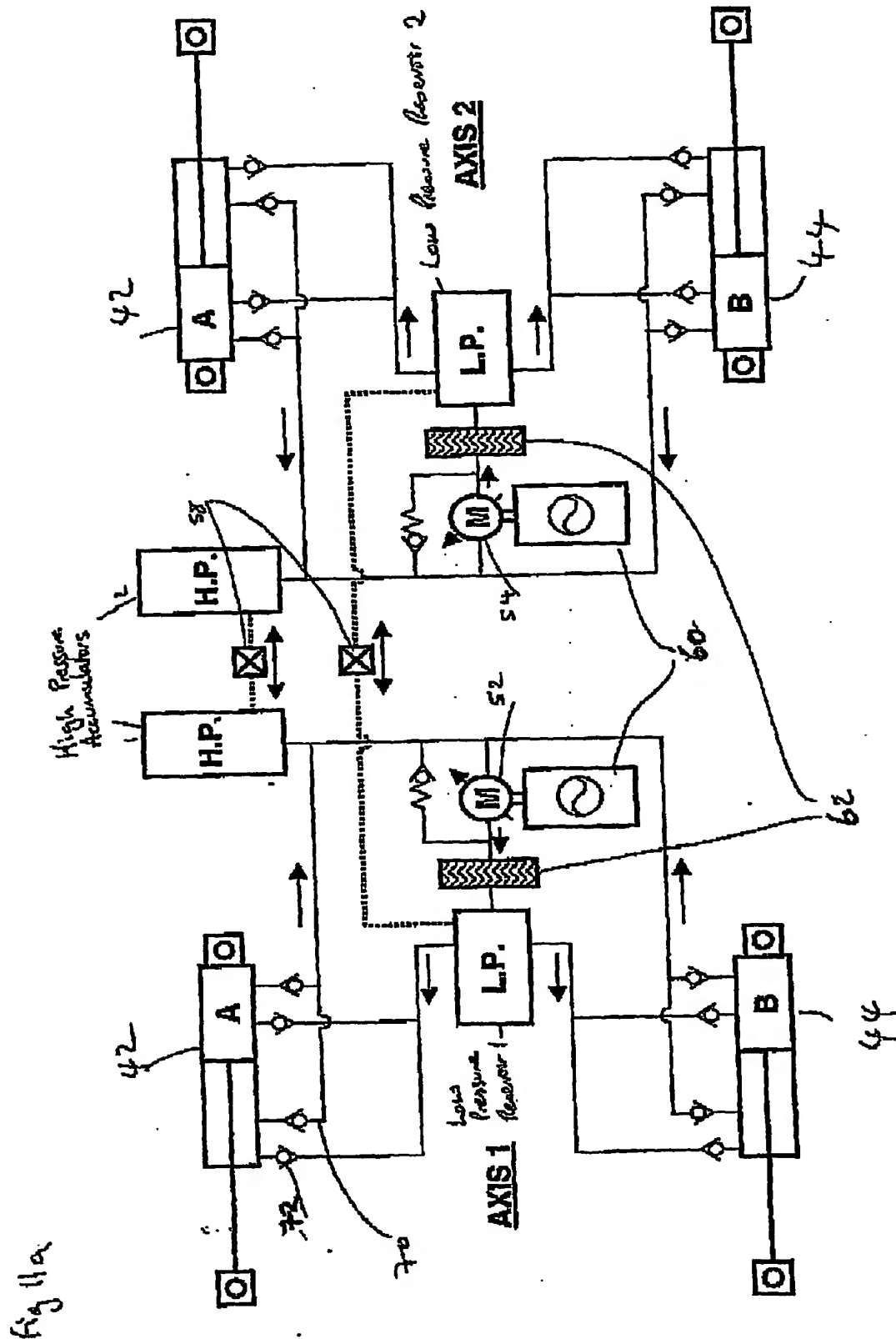


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Fig 10



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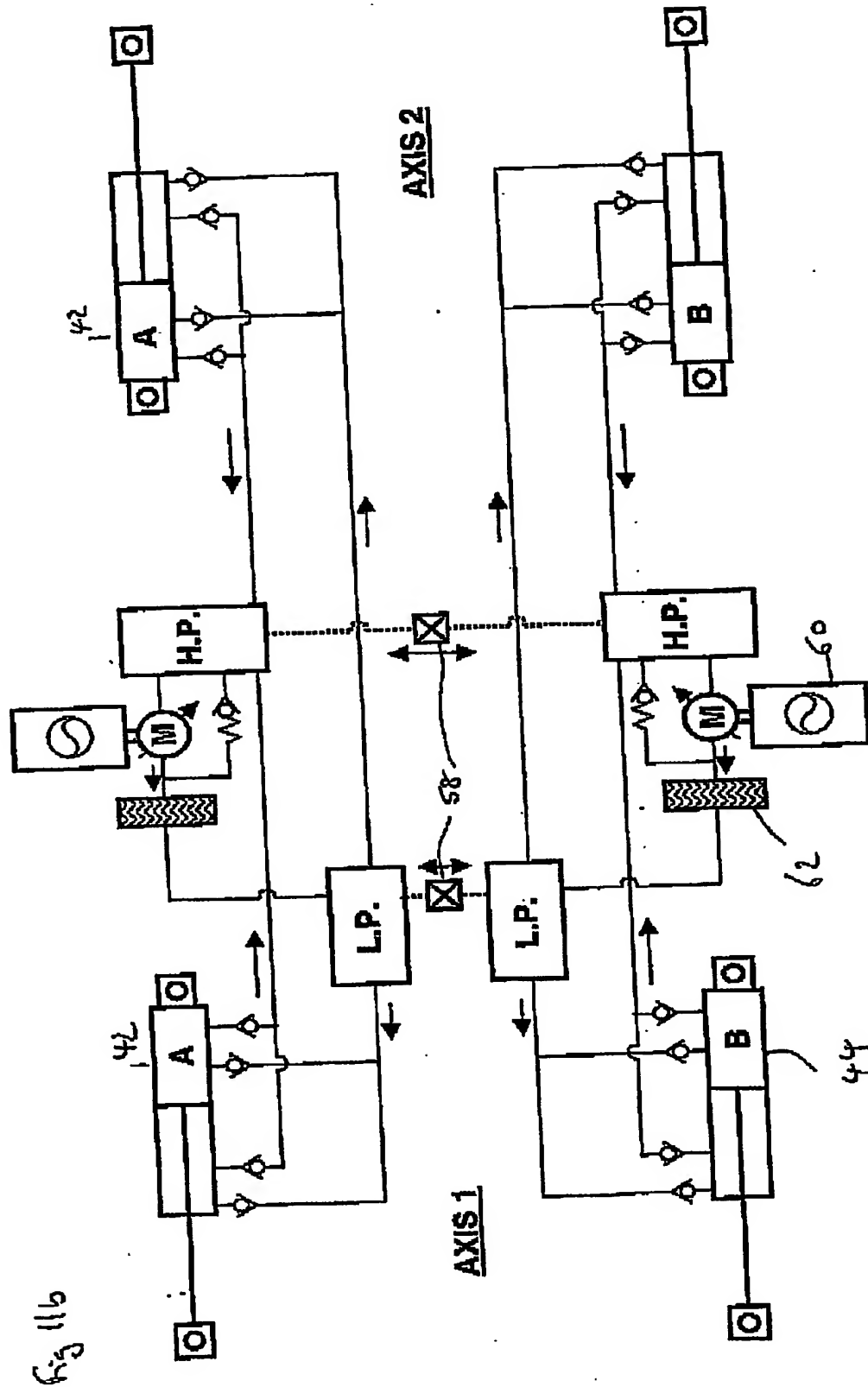
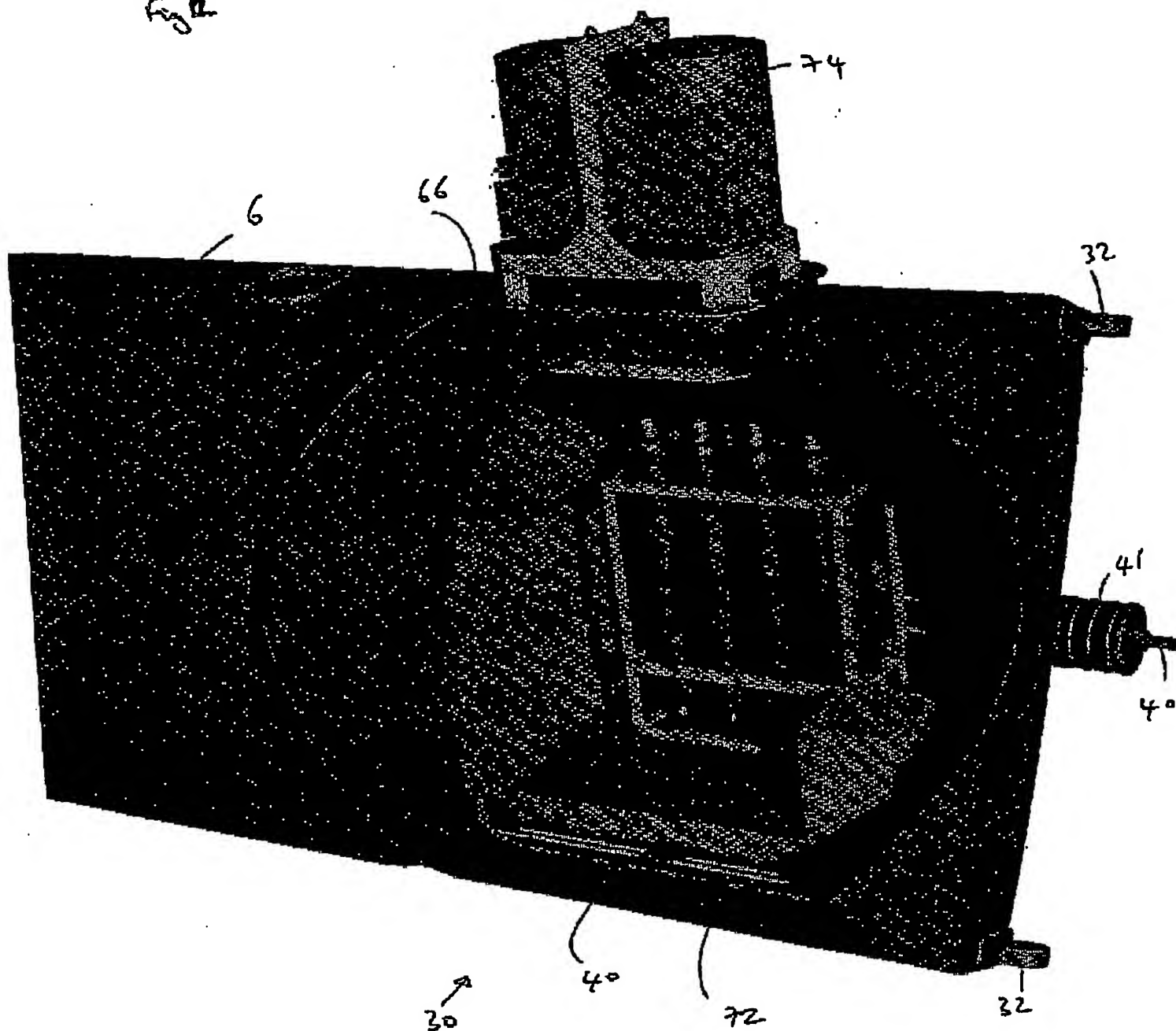


Fig 11b

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Fig 12



**PCT/GB2004/001443**



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